Showalter's formula [1] for computing precipitation rates from a column of pseudo-adiabatically ascending air is

$$I = \frac{V_{z_0}\rho_0(x_0 - x_1)}{7} \tag{1}$$

where I is the precipitation rate (in./hr.), V_z is the vertical speed (m./s.), ρ_0 is the air density (kg./m.^{3}), and x is the mixing ratio (g./kg.), the subscripts 0 and 1 referring to the base and top of the air column, respectively. For a column with base at 10,220 ft. and top at 20,000 ft. and the preceding assumed conditions of wind, temperature, and humidity, equation (1) yields

$$I = \frac{1.3 \times 0.898(2.54 - 0.38)}{7} = 0.36 \text{ in./hr.} \tag{2}$$

or 8.64 inches in 24 hours, which is about 176 percent of the amount estimated to have fallen. These computations indicate the 24-hour 76-inch snowfall is theoretically possible under the assumed conditions even if the snow density were as high as 0.11.

Also, it should be noted that Brooks [2] once roughly estimated that the maximum possible 24-hour fall of snow with density of 0.10 under normal packing conditions would be approximately 6 feet. Since the density of the snow at Silver Lake was appreciably less than 0.10, the prorated 76-inch 24-hour snowfall appears to be meteorologically possible.

The storm of April 14–16, 1921 was outstanding for the region. Thunder was reported at several widely scattered stations, indicating widespread convective activity. Fremont Experimental Station reported, "Heaviest snow of record on the 14th and 15th and only one ever recorded as breaking many trees." Referring to Denver, the Denver Post reported that, with a total snowfall of 11 inches and precipitation of 1.73 inches (part of which was rain), the April 14–15 storm was the second worst April blizzard since 1885. Snow drifted to a depth of 7 feet in many parts of the city. The Moffat road was tied up with drifting snow 8 feet deep just west of Corona. The storm was the worst in 5 years at Colorado Springs, where 19 inches of snow were reported. Splintered telephone and telegraph poles were strewn all the way from Denver to Colorado Springs.

CONCLUSION

The above considerations lead to the conclusion that the Silver Lake measurement is reasonable. There is no evidence to indicate that it was less accurate than the measurement of the snowfalls that until now have been accepted as record values, which, incidentally, have been exceeded several times if estimates by Weather Bureau personnel experienced in mountain snowfall are accepted as reliable. For these reasons, the Silver Lake snowfall is being accepted as providing the highest known rates in the United States for durations to 4 days.

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CORRESPONDENCE

REMARKS ON "ON THUNDERSTORM FORECASTING IN THE CENTRAL UNITED STATES"

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The technique for forecasting thunderstorms at Chicago described by Means (MONTHLY WEATHER REVIEW, vol. 80, No. 10, 1952, pp. 165–189) is not dependent upon a rigid geographical reference frame for the data determining the forecast, and therefore it is in order that an evaluation be made of its effectiveness at other stations in the central United States. For this purpose, forecasts for each day of June, July, and August, 1952 were made for the following nine stations in addition to Chicago itself: St. Cloud, Minn. (STC), North Platte, Nebr. (LBF), Dodge City, Kans. (DDC), Omaha, Nebr. (OMA), Columbia, Mo. (CBI), Dayton, Ohio (DAY), Oklahoma City, Okla. (OKC), Little Rock, Ark. (LIT), and Nashville, Tenn. (BNA). Results strongly suggest that local forecasters, particularly in the North Central States, may benefit from studying the article and putting the technique into routine use at their stations as an aid in forecasting thunderstorms during the coming summer months.

Through the use of Means' technique, 920 forecasts were made, one for each of the ten stations for each of the 92 days. These were verified by using original airways reports from the individual stations, and the requirement for verification is the same as that used by Means—thunder heard at the station between 1230 CST of the forecast day and 1230 CST of the following day.

Experience in applying the three stratifications required to make a forecast gives rise to the following remarks. The first stratification, which consists of classifying the case into 1 of 11 types or subtypes depending basically on the temperature advection pattern at 850 mb., requires clarification in borderline cases. In such cases, it is best to select the type which is moving toward the station. When this cannot be done, and one of the possible types is favorable for thunderstorm occurrence, then that type should be selected so that the final forecast may be determined by further stratification.

The second stratification need be applied only to cases which have first fallen into a type favorable for thunderstorm occurrence. It consists of the examination of surface maps for the occurrence of thunderstorms within certain areas in the twelve hours preceding the time of the forecast. In the most frequently occurring of the types favorable for thunderstorms, the pre-trough warm advection type, the area used is a triangle whose altitude must be oriented along the bisector of an angle between contours and isotherms at 850 mb. It is often found necessary when gradients are weak to draw contours for every 20 feet and isotherms for every degree in order to get an angle of intersection reasonably near the station.

When thunderstorm activity is found in the prescribed area, the final stratification is required and is made by reference to a critical line on a chart of lapse rate between the 850- and 500-mb. levels vs. dew point at 850 mb. (fig. 37 of Means' paper). However, it seems that the usefulness of the critical line must depend on the actual 850-mb. temperature if we are to have a real measure of convective instability. Thus the critical line, which on this stability-moisture diagram has been selected as the locus of 40 percent incidence of thunderstorms, would not be expected to indicate the same frequency in abnormally warm seasons such as the summer of 1952 or in areas where the mean temperatures are higher than those at Chicago. Both of these factors were present in this test with the result that the critical line on the average represented a mere 25 percent incidence of thunderstorms, a level not usually acceptable to the forecaster. This difficulty was anticipated by Means who in correspondence suggested that we check whether the Showalter stability index might prove to be a successful substitute for the stability-moisture diagram.

First, a test was made to find whether both second and third stratifications are essential to the system. For the 397 cases which go beyond the first stratification by falling into one of the four favorable types, a skill score of 0.18 is attained by the use of both second and third stratifications. If either of the latter is eliminated and the final forecast made by the remaining one, the skill score falls to 0.10. When the final forecast for the 304 cases reaching the third stratification is made, not with Means' stability-moisture chart but instead by requiring a Showalter stability index of zero or less, computed at the same geographical location from which data are taken for the stability-moisture chart, a skill score of 0.23 is attained. This indicates that the stability index may profitably be substituted for the stability-moisture chart in cases reaching the third stratification.

The accompanying figure 1 shows the stability-moisture chart for Chicago with the stability index plotted for each case. At least for this abnormally warm summer season, the stability index permits a no-thunderstorm forecast to be made at Chicago for a group of cases lying on the high side of the critical line and having only an 18 percent incidence of thunderstorms. As shown in table 1 the use of the index tends to increase the percentage of correct forecasts.

TABLE 1.—*Results of applying Means' technique to ten stations in the central United States. Columns give the number of cases according to the code: A, thunderstorm forecast and observed; B, thunderstorm observed but not forecast; C, thunderstorm forecast but not observed; D, no thunderstorm forecast or observed. The percent correct is calculated from $(A+D)/92$. The last column is the percent correct from similar columnar data, A and D, for forecasts determined by substituting a Showalter stability index of zero or less for the 40 percent discriminating line of the stability-moisture diagram in the third stratification of the Means technique*

	Original Means technique					With Showalter S. I. substituted
	A	B	C	D	Percent correct	Percent correct
Chicago	14	3	24	51	71	82
St. Cloud	17	11	14	50	73	73
North Platte	18	13	11	50	74	72
Dodge City	13	9	18	52	71	71
Omaha	16	19	26	31	51	60
Columbia	16	11	14	51	73	74
Dayton	10	10	10	62	78	78
Oklahoma City	6	8	20	58	70	73
Little Rock	2	17	10	63	71	76
Nashville	7	12	15	58	71	74
Total	119	113	162	526	70	73

The relative success of the forecasts for each of the stations is indicated by the data in the table. An attempt was made to find one or more reasons for the poor showing made by the technique at Omaha. No general conclusion could be made beyond the observation that the failures occurred with rapidly changing types thus suggesting that the forecaster lean toward use of an incoming type. A few additional failures could be traced to subsequent development of thunderstorms in pre-frontal troughs which were dry at the time the prescribed area was checked for past thunderstorms.

The period covered by this test was not a long one but

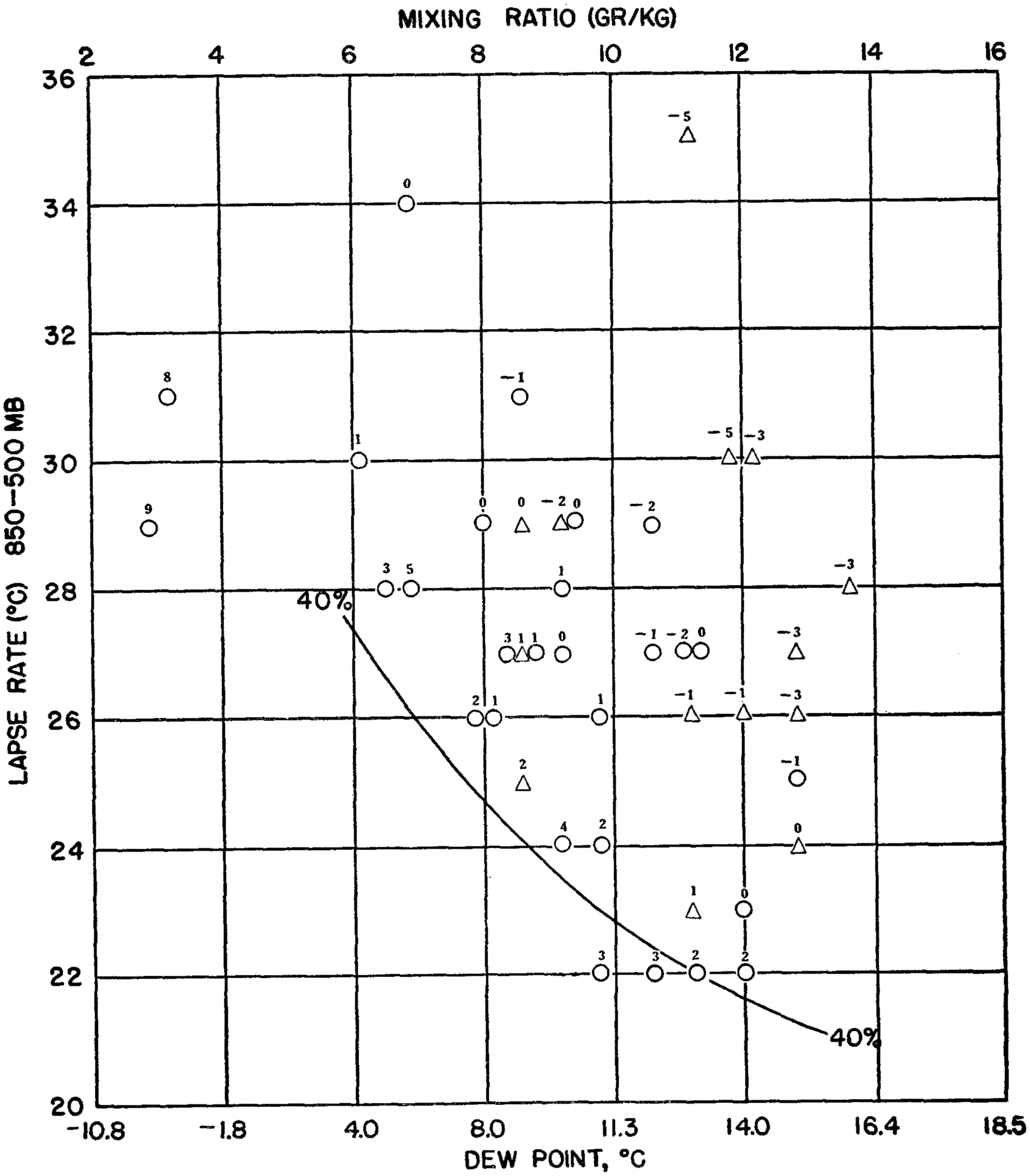

FIGURE 1.—Stability-moisture diagram (after Means) with 40 percent line based on relative frequency of thunderstorms in cases from June 1946–47 and July–August 1945–46–47 which are not separated out in the first two stratifications. The cases shown here are for Chicago during June–August 1952. Triangles represent thunderstorm cases, circles are no-thunderstorm cases. The Showalter stability index is included for each case.

the results certainly indicate that Means' technique will be found helpful at many stations in the Central United States. The relatively low percentage of times thunderstorm forecasts verify at Oklahoma City, Little Rock, and Nashville may be seen in table 1 by comparing column A with the sum of columns A and C. This low verification at the three southernmost stations may be a result of a climatic difference in the ratio of air mass to prefrontal thunderstorms or merely of the abnormality of the season, but in either case invites further study.

This evaluation was made at the suggestion of Mr. R. A. Allen, Chief, Short Range Forecast Development Section. Mr. Sidney Teweles, Jr. of this Section aided in reporting the results.